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INCLINED PARABOLIC COLLECTOR FOR SOLAR THERMAL POWER GENERATION

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Abstract-*Concentrating solar thermal technology uses large sun tracking mirror to concentrate solar radiation. Among the different concentrating solar thermal technologies, parabolic technology is the best for its low cost even in the small generation. This paper presents an inclined parabolic shaped reflector that focus the sun's direct beam radiation on a linear receiver located at the focus of the parabolic collector. The concentrating solar collector has been designed for producing superheated steam at 130^{0}c under 2 bar pressure by heating water from 30^{0}c. The collector is a cylindrical parabolic shape of 1.5m aperture and 3.08m long The required steam condition were measured and the values were used in the necessary calculation required for designing a 2.5KW solar thermal power plant.*

Keywords: Solar thermal, Solar radiation, Solar collector, Collector efficiency.

1. INTRODUCTION

Solar energy is very vast, inexhaustible source of energy. The power from the Sun intercepted by the earth is approximately 1.8×10^{11}MW [1], which is many thousands of times larger than the present consumption rate on the earth of all commercial energy sources. Thus solar energy could supply all the present and future energy needs of the world on a continuing basis. This makes in one of the most promising of unconventional energy sources. Roughly 35 percent of solar radiation is reflected back into space, another 18 percent is absorbed by the atmosphere and about 47 percent reaches the earth.

The solar thermal power generation does not create any carbon dioxide and other greenhouse gasses, compared to other electricity generation. So the solar energy has to be utilized in a maximum way. But unfortunately at present peoples around the world have been able to use only one fifth of the total energy used from solar resources. However efforts are being made to release it 75% of the total global energy budget by the year 2025[2].

Among the solar thermal applications electric power generation is the best. In solar thermal power plant, the concentrated solar energy can be used alone or with conventional fuel to run steam turbines for large scale power generation. Solar thermal energy plants have been investigated since about 20 years in three different variants: parabolic trough power plants, solar dishes and central receiver power plants [3-5]. Until today only the trough variant has been built and operated in commercial scale and under commercial conditions.

The reflective surface of a parabolic trough concentrates sunlight onto a receiver tube located along the trough's focal line, heating the fluid flowing in the tube which is then transported through pipes to a steam turbine coupled to the generator to produce electricity [6]. The troughs are normally designed to track the sun along one axis, predominantly north-south [7-9].Several improvements of this technology have been made in last few years.

In the proposed design for solar thermal power generation, receiver tube is divided into three chambers. Water is used instead of heat transfer fluid. Water becomes saturated steam by absorbing solar thermal energy in the first chamber. This saturated steam is filled in the rest two chambers; here it becomes superheated by absorbing solar thermal energy. This superheated steam finally comes out of the tube under certain pressure, as there is a pressure check valve at outlet.

2. DESCRIPTION OF THE COLLECTOR

An illustration of cylindrical parabolic solar concentrator design and construction is shown in Fig.1 The collector consists of a cylindrical parabolic reflector, glass envelope, receiver tube; supporting frame with sun tracking system. The concentrator shown is a normal aluminium reflector having the shape of a cylindrical parabola. It focuses the sunlight onto its axis where it is absorbed on the surface of the absorber tube and transferred to the fluid (water) in it. In order to that, the sun's rays should always be focused on to the absorber tube, the concentrator has to rotate.

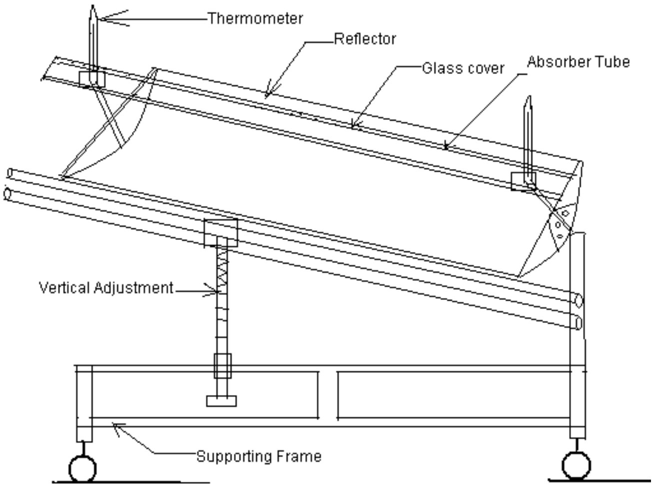

Fig.1: Schematic diagram of the parabolic solar collector.

A concentric glass cover around the absorber tube helps in reducing the convective and radiation losses to the surroundings. The receiver tube is located in the centre of the envelope and is installed at the focal line of the reflector. The receiver tube is coated with black paint. The reflector frame is constructed, considering the conditions that should have minimum weight and high wind load resisting and the aluminium sheet reverted on it. For the purpose of collecting a maximum amount of solar energy the performance of the collector is of importance because it has a significant influence upon the efficiency of the whole system. Therefore each component of the concentration that is reflector, receiver tube with selective surfaces and tracking system have been carefully designed and constructed within the available sources and technology. The important conditions have to be considered in the design are – a. The shell and structure must be supported in various positions of orientation without significant distortion because of its own weight; b. they must be capable of being operated and therefore not significantly distorted in commonly encountered winds; c. They must be capable of resisting structural damage in light winds and other storm conditions

3. REFLECTOR DESIGN

The reflector is 3.08m in length and 1.5m in width, it is tilted with an angle when facing south. It is mounted on a base constructed steel bars. It can be rotated about its center to track the sun's motion manually. It is made of normal aluminum sheet. The solar concentrator is designed on the basis of the following assumptions.

1. The reflecting surface is continuous and perfect parabola.
2. There occurs perfectly axial incidence of solar radiation on the concentrator surface.
3. Specular reflection exists all over the reflector.
4. Reflectivity is constant all over the reflecting surface independent to incidence angle.
5. There is uniform radiation intensity all over the solar concentrator.
6. The apparent angular diameter of the sun, given the symbol 2θ, is constant at 32 minute of angle.
7. The target of the concentrator is infinitely thin with both its sides in the focal plane. The centre lines, of the target coincide with the focal line of the parabolic cylinder .Losses from the target due to reflection and by different modes of heat transfer are not considered. With the above mentioned points in mind we can go for analysis of the concentration phenomenon.

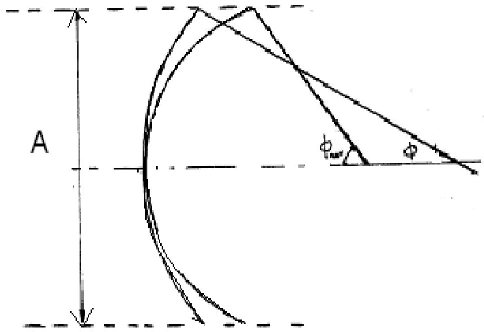

Fig.2 : Schematic cross-sectional view of the cylindrical parabolic solar with rim angle φ_{max} showing reflection from a position angle of φ.

Reflection of radiation occurs from various points of the parabolic surface. Due to angular diameter of sun the reflected rays from a cone; within this cone of radiation incident on any point at a position angle of Φas shown in Fig.2. The incident angle varies from *(Φ/2-θ),* for the inner ray to (Φ/2+θ) for the outer ray. The ray show is very nearly incident on the edge of the reflector; at the edge Φ is Φ_{max} , the rim angle, and r are r_{max} . The distance r from a point on the reflector to the focus can be derived for the particular reflector shape. For a reflector of parabolic section, the focal length is defined by the equation [9] of the surface

$$y^2 = 4fx \qquad (1)$$

$$r = \frac{2f}{(1+\cos\phi)} \qquad (2)$$

The cone of radiation reflected from any point other than the apex intersect the focal plane in an ellipse, i.e. normal to the axis of the concentrator, the width *W'* is equal to (wi+wo). It can be seen from the Fig.3.

$$W_i = \frac{\theta\sec\phi}{(1+\tan\theta\tan\phi)} \qquad (3)$$

$$W_o = \frac{r\tan\theta\sec\phi}{1-\tan\theta\tan\phi} \qquad (4)$$

$$W = \frac{2r\tan\theta\sec\phi}{1-\tan\theta\tan\phi} \qquad (4)$$

If both Wi and Wo are less than W/2, all the radiation will be intercepted by the target. If one of them is greater than *W/2*, the part of the radiation will miss the target at both edges. However If both w_i and w_o are less than W'/2, all the radiation will be intercepted by the target. If one of them is greater than *W/2*, the part of the radiation will miss the target at both edges. However it is not wise to increase the target width more, because in that case the shading effect becomes prominent. This is because a part of the reflecting surface dose not receives any of the direct incident radiation since it shaded by the target. Thus when the shaded effect is considered, the power increases up to a maximum value (power received) than drops, upon further increase of B = (W/w) down to zero at a certain value of B where Ψ = θ. The value of the target width ratio (B) at which maximum energy is obtained is known as thermal optimum width and its value is given by the flux density distribution varies over the width of the target. It has uniform maximum value of the middle of the target. It is not wise to increase the target width more, because in that case the shading effect becomes prominent. This is because a part of the reflecting surface dose not receives any of the direct incident radiation since it shaded by the target. Thus when the shaded effect is considered, the power increases up to a maximum value (power received) than drops, upon further increase of B = (W/w) down to zero at a certain value of B where Ψ = θ. The value of the target width ratio (B) at which maximum energy is obtained is known as thermal optimum width and its value is given by the flux density distribution varies over the width of the target. It has uniform maximum value of the middle of the target.

The aperture area of the concentrator (2b) is 1.5m and solar image width (i.e., outside diametre of the absorber tube) is 0.029m. The best rim angle ϕ_{max} can be calculated as

$$\frac{b}{w} = \frac{Sin2\phi_{max}}{4\tan 16'} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Again, maximum mirror radious

$$r_{max} = \frac{b}{Sin\phi_{max}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

The calculated focal length and ϕ were found 0.481 and 75.61^0 respectively.

3.1 RECEIVER TUBE DESIGN

The receiver diameter is proportional to the distance from the reflector. The thermal losses are directly proportional to the receiver diameter, so that obvious goal in receiver tube sizing is to assume an optimum value and then calculation is done to select a parabolic ring angle, which would result in the smallest maximum distance from parabola to focus. The equation [5-6] give two values of rim angle corresponding to simple assumed vales of tube diameter and for same common aperture. We used the larger rim angle to get the smallest distance from the focus to parabola.

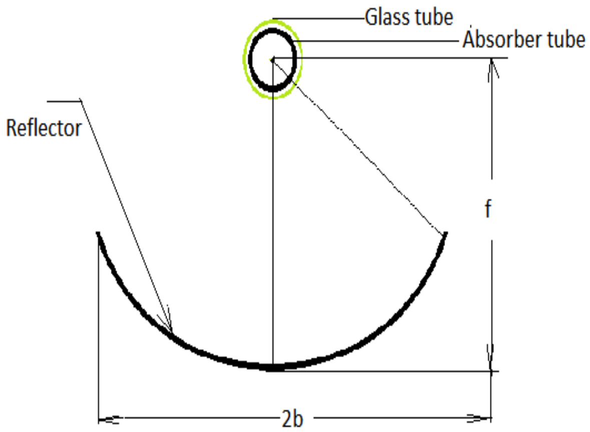

Fig.3: Basic geometry of absorber and collector .

Another influencing factor in an effective collector design is the accuracy with which the tube focal line can be determined and the placement of the receiver tube in that line. There is every possibility of miss-location of the receiver tube in the focal line. The usual way to compensate for miss-location is to make the receiver tube slightly larger without a significant efficiency penalty. Inside and outside diameter of copper tube are 24mm and 29mm respectively. The tube surrounded by concentric glass cover that has an inside and outside diameter of 0.049m and 0.055m respectively.

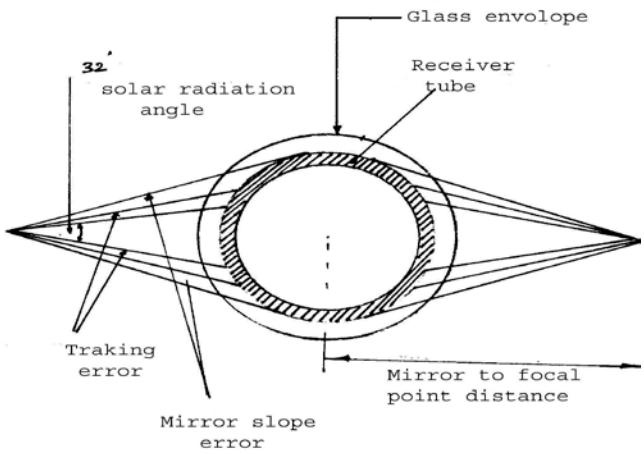

Fig.4: Receiver tubes assemble cross section.

In the case of high performance collector, the absorber tube is coated with a selective surface like black-paint, blackened nickel and so on. Blackened nickel has low values of eminence and a high value of absorptance. Although, black-paint has a high value of emittance and a low value of absorptance, it is selected in the proposed design for its low cost. Finally, A cylindrical parabolic Collector mainly consists of the following components which are given bellow with their criteria.

Table.3.1. Design parameters for the collector

SL. NO.	Parameters	Dimension
1.	Aperture area	$4.4506m^2$
2.	Rim angle	75.61^0
3.	Absorber tube dia.	0.029m
4.	Annular gap	0.0 2m
5.	Concentration ratio	13.5
6.	Length	3.08m

The absorber tube is made of copper tube and surrounding by glass cover. The inside and outside diameter of the absorber tube is 0.024m and 0.029m respectively. It is designed on the basis of the following assumptions

(a) All the energy reflected from the parabola is to be collected.

(b) Placement of the tube will ensure the smallest distance from parabola to focus.

As the mass flow rate is continuous throughout the system, hence flow rate can be calculated as

$$A_p = \frac{m_s[C_{p_w}(t_{sat} - t_w) + h_{fg}]}{\eta_{overall} \times I_{DN}} \qquad \text{.................(8)}$$

As 2 bar pressure is to be maintained at the outlet of the tube, necessary dead mass required can be calculated as 0.144 kg at mass flow rate 0.3768 kg/hr.

4. RESULT AND DISCUSSION

Performance test of the designed collector was carried out and evaluated. The experiment was performed over several days during the month of June. The collector was placed in the sunny area. A blacken absorber tube containing water, was placed on the focus point. The light from the sun falling on the collector reflected on the focus. The arrangement was set according to the position of the sun by tracking. After absorbing solar thermal energy water became saturated steam and then superheated steam. This superheated steam finally came out of the tube under certain pressure. All the temperature was measured by thermometer, pressure by steam pressure gauge and flow rate by steam flow meter. The collector efficiency is calculated as follows,

$$\eta_{overall} \; \frac{m_s[c_p(t_{sat} - t_w) + h_{fg}]}{I_{DN} \times A_p} \qquad \text{....................(7)}$$

It is seen that, temperature time curve increases to a point then decreases. This is due to the fact the direct normal radiation is not constant throughout the day. It increases up to the solar noon, then decreases. At noon the direct normal radiation is maximum. The diffuse beam component of the solar radiation is lost in a concentrating solar collector, only the normal beam component of the solar radiation has been considered in calculating efficiency. The average available beam radiation received by the collector during the noon period on both days was about 2160KJ/hr-m^2. From Fig.5-8, it is seen that the efficiency (based on the beam component only) drops at the higher outlet temperature. So, it may conclude that efficiency decreases with the increase of temperature.

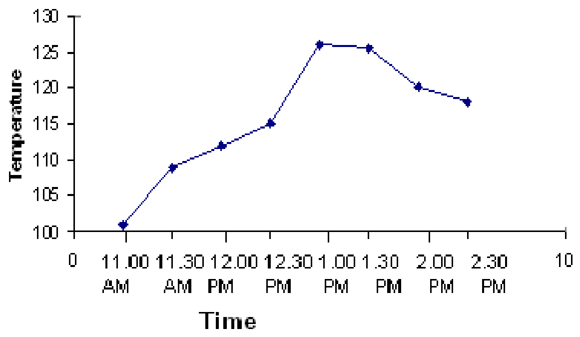

Fig: 5: Variation of temperature with time.

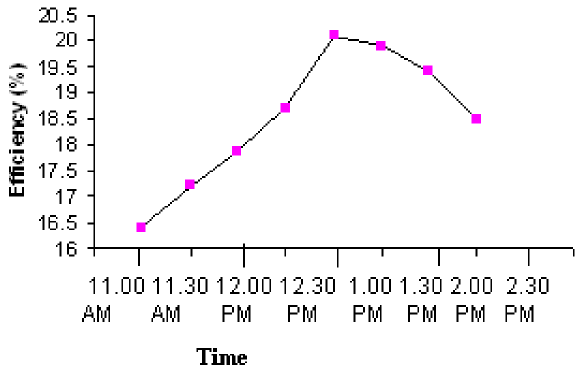

Fig.6: Variation of efficiency with time

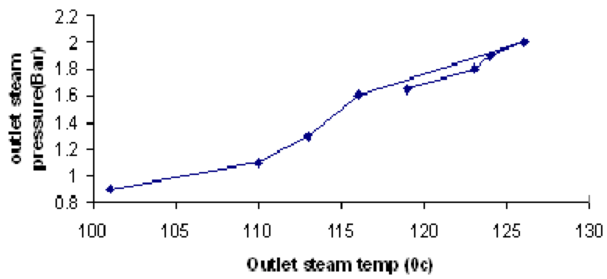

Fig: 7: Variation of steam pressure with Temp.

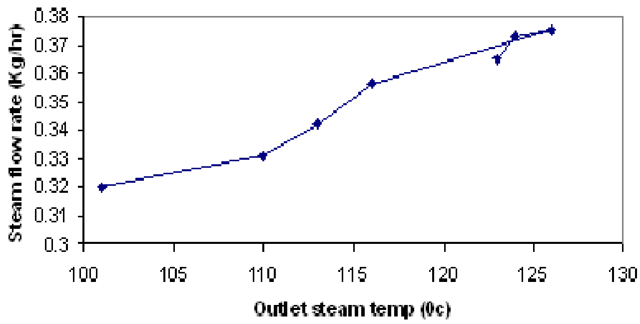

Fig: 8: Variation of steam flow rate

Maximum temperature of the steam was 126^0c under 2 bar pressure at a flow rate of 0.375Kg/hr. To make the collector cheapest, normal aluminum sheet, synthetic black paint, as a selective surface was used. Impurities of the aluminum sheet and low emittance of the selective surface kept the operating temperature low. Anti-reflecting coating was not used and the space between the glass cover and absorber tube was not evacuated. Although, no use of anti-reflecting coating and no space evacuation reduced the construction cost but increase the heat loss and subsequently kept the operating temperature low.

5. CONCLUSION

Cylindrical parabolic solar collector is widely used today. For its small receiver surface area, this leads to low heat loss. The collector's high-energy yields result also from its tracking system. Cylindrical parabolic solar collector catches the sun radiation in the morning until the late evening. But, the collector is relatively insensitive to rise the absorber fluid temperature and has not yet been improved to produce superheat steam from water of ambient temperature. Along with some other advantages, the designed solar collector is able to produce superheat steam from water of ambient temperature. This collector also facilitated with the pressure flexibility. Besides these, to keep the construction cost low, the cylindrical parabolic solar collector is constructed using locally available materials.

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8. NOMENCLATURE

Symbol	Meaning	Unit
A_p	Aperture are	(m^2)
h_{fg}	Enthalpy of evaporation	(KJ/Kg)
2b	Aperture	(m)
$\eta_{overall}$	Overall efficiency.	
$D_{o.g}$	Glass envelop outside dia.	(m)
I_{DN}	Direct solar radiation intensity	(W/m^2)
L	Length of the absorber tube	(m)
W	Solar image size	(m)
ϕ	Rim angle	$(^0)$
C_{pw}	Specific heat of water	$(KJ/Kg/^0K)$
m_s	Mass flow rate of water	(Kg/sec)
r_{max}	Maximum mirror ratious	(m)
t_{sat}	Saturation temp of the steam	(^0c)
f	Focal length of collector	(m)
t_w	Temp. of the water	(^0c)